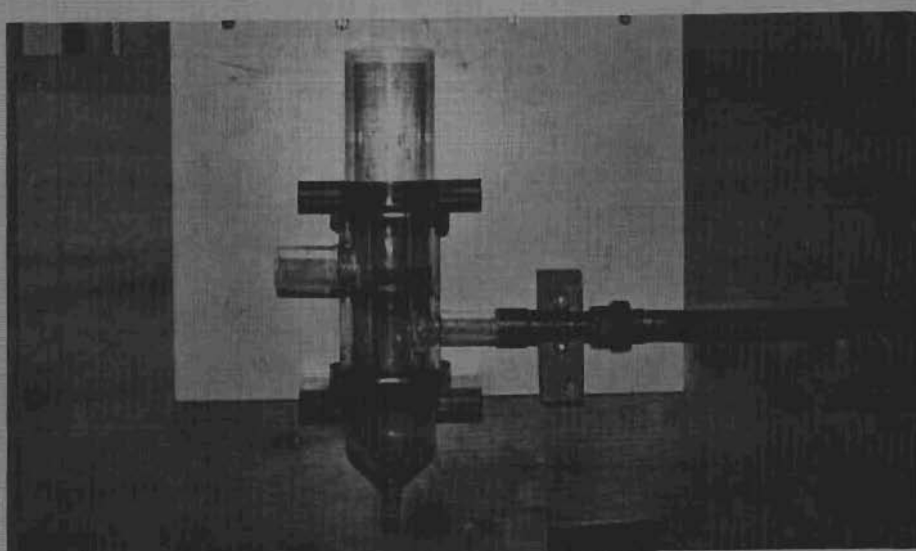
MIRL Report No. 55

APPLICATION OF HYDROCYCLONES FOR RECOVERY OF FINE GOLD FROM PLACER MATERIAL



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Final Report

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NOTICE

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Office of Surface Mining or of the U.S. Government.

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Introduction

Alaska and other gold areas have seen a sharp resurgence of placer mining in the last few years. Mines using sluice boxes usually recover gold down to 100 mesh, but recovery of gold finer than this size is a function of particle shape factor, sluice box design and operating parameters. It is felt that a concentrating device is needed to recover gold finer than 100 mesh that may not be recoverable in a sluice box. The device should be capable of processing a large volume of water and solids discharged from the sluice box. Compound water cyclones, successfully used in the coal processing industry, seem to offer solutions. A system using these devices could recover a concentrate which would be one twenty fifth the size of the original solids in a two stage process. It is not intended to produce a finished product with cyclones, but to reduce bulk so that the reduced concentrate, free of slimes, could further be treated by flotation, gravity methods, or cyanidation to isolate the gold. This report addresses only the application of hydrocyclones for concentrating gold from placer material.

Concentration Cyclones - History and Principles

The hydrocyclone is a device used in the treatment of aqueous mineral suspensions for the purpose of wet separation. The basic structure is that of a tapering, hollow body or cone. The fluid stream is introduced tangentially through a peripheral inlet and is transformed into a spiral flow moving from the inlet to the apex. The taper induces a back flow along a central core which spirals toward the inlet section, while the high centrifugal accelerations of the vortex cause the particles to separate and move in the direction of the apex (4).

The centrifugal force developed accelerates the settling rate of the particles (there is evidence to show that Stokes' law applies with reasonable accuracy to separations in cyclones of conventional design), thereby separating particles according to size and specific gravity. Faster settling particles move to the wall of the cyclone where the velocity is lowest and migrate to the apex opening (5,6).

Many determining factors control the direction of flow of a particle in a hydrocyclone. Dreissen and Fontein, (5) list the following:

1) Shape of particle
2) Solids concentration
3) Feed pressure
4) Back pressure
5) Cyclone diameter
6) Diameters of the feed opening
7) Overflow opening
8) Apex opening
9) Length of the cylindrical part (vortex finder)
10) Cone angle

11) Specific gravity
12) Average grain size of the particle
13) Solids concentration of the inlet feed and apex discharge
14) Viscosity of the feed suspension and the liquid

Historically the main use of cyclones in mineral processing is as classifiers. These have proved extremely efficient at fine separation sizes. They are used increasingly in closed circuit grinding operations but they have found many other uses, such as desliming, degritting and thickening, and recently for concentrating.

It has been shown that under the best conditions, satisfactory separation with a conventional cyclone can be obtained for coal cleaning only up to 1.6 specific gravity (7,8). The results obtained with single CW Cyclones show that their applicability is not restricted to cleaning coal of up to 1.6 specific gravity, but covers the entire range of cut points. In addition, it has been found that the presence of a hindered settling bed enables the processing, in unstable suspension, of mineral sands and ores (7).

However a cyclone cannot efficiently both classify and concentrate feed. It is not possible for a given cyclone to perform both functions simultaneously at maximum efficiency—an increase in classification efficiency automatically results in a decrease in concentration efficiency. This correlation between concentration inefficiency and classification efficiency is understandable when one considers that, for high concentration efficiency, the cyclone is expected to make a separation in which coarse, light particles report to the overflow, and fine, heavy particles (gold-pyrite for example) report to the spigot at the apex. This is contrary to the normal tendency of the cyclone to act basically as a classifier (9).

Recent years have seen the development of various cyclones specifically for concentrating purposes. Their physical design is such that classification effects are suppressed and the influence of particle specific gravity is maximized. These are not heavy-medium cyclones, which have been in use in the mineral processing industry for some years, but true hydrocyclones. They were developed largely as a result of work in the coal industry (8), where cyclones operating with a water medium are now in wide use for upgrading fine coal. Investigations have also been carried out into the use of cyclones for the beneficiation of cassiterite (10,11) and iron ores, and a recent Russian paper (12) describes the concentration of gold from milled conglomerate ores by use of a short cone hydrocylone (9).

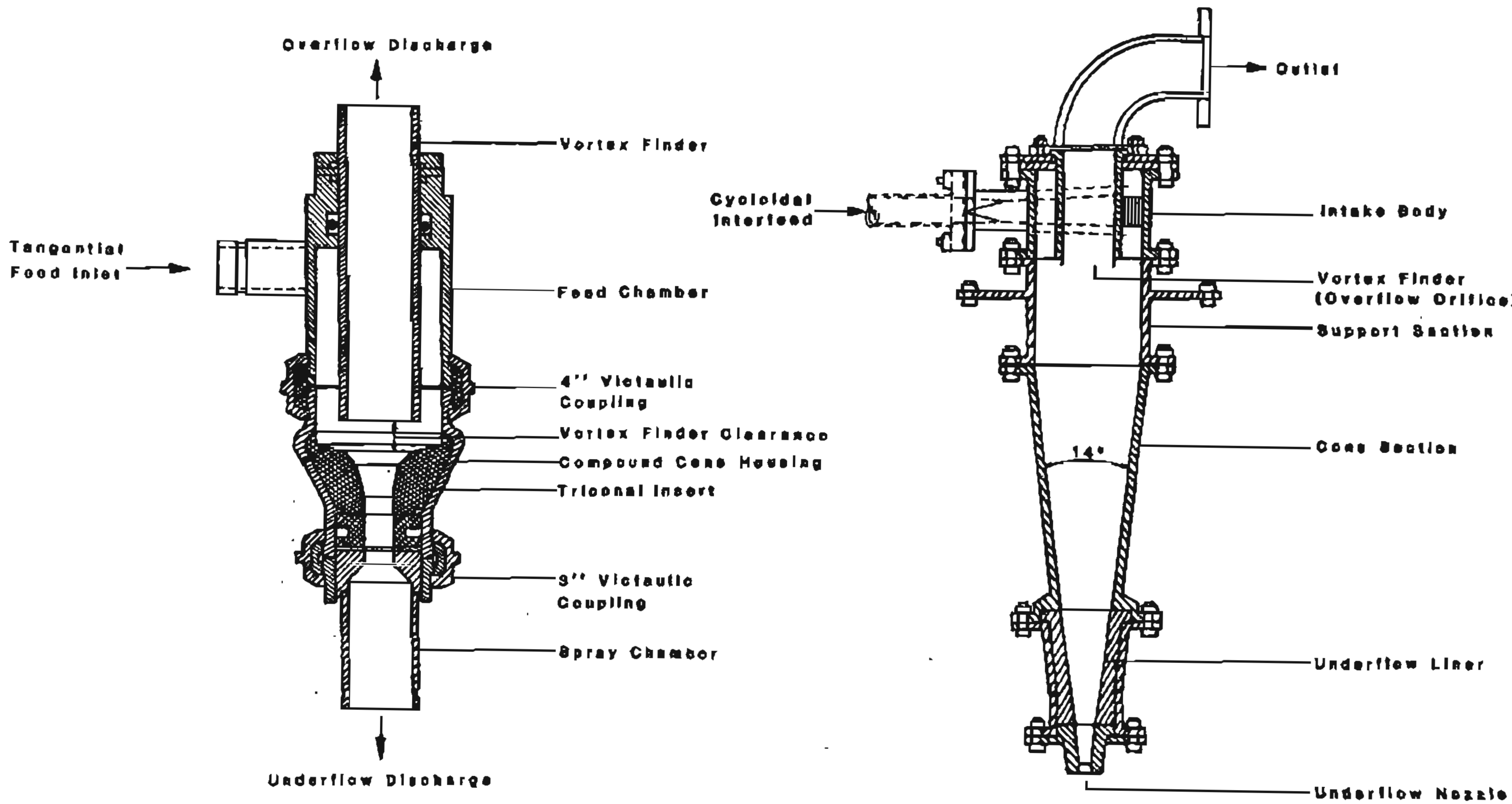
Classification cyclones are of slender design, with a narrow cone angle—usually 15 to 30 degrees. In these cyclones, the particles must discharge either through the vortex finder or the apex orifice, and the basic requirement for separation is the achievement of balance between the centrifugal forces accelerating the particles radially outward and the centripetal drag forces. For this purpose, relatively large vortex finder clearances are common in classification cyclones, because this assists in providing the time for particles in the central flow region to reach their terminal free settling velocity relative to the entraining water (9).

In contrast, concentrating water hydrocyclones are of squat design, with a wide cone angle—in the range 60 to 180 degrees—and long large diameter vortex finders. They are called compound water (cw) cyclones because of the compound slopes to their sides. They are operated to suppress classification phenomena in favor of gravity concentra tion effects. Briefly, their design is based on two hypotheses (8): (a) a particle bed stratifies according to density along the conical wall of the lower cyclone section, and (b) particles entering the central spiral flow separate during the initial phase of their acceleration in a radial direction. The former hypothesis has led to the selection of wide cone angles for concentrators, because particles stratify more reliably along the shallower wall of a wide cone than would be possible along the steep wall of a slender cone. The latter hypothesis has led to the preference for relatively short vortex finder clearances in concentrators, because this design assists in separating particles that swirl toward the vortex finder before the centrifugal mass and the centripetal drag forces acting on these particles attain equilibrium. Since it is the drag force that increases the relative influence of particle size on separation, this force must be suppressed in the operation of cyclones as concentrators (9). Figure 1 shows the basic design of each type, classifying and concentrating.

The CW cyclone has been described by Visman (7) as having three effective sections as shown on Figure 2. Particles of different sizes and specific gravity form a hindered settling bed in Section I of the compound cone. Light, coarse particles are prevented from penetrating the lower strata of this bed by the coarse, heavy fractions and by the fine particles filling the interstices of the bed. Consequently, the water passing from the periphery of the cyclone chamber towards its main outlet (the vortex finder) erodes the top of the stratified bed and substantially removes the light, coarse particles via the "central current" around the air core.

The remainder of the bed is forced into the second conical section (II) by new feed entering the cyclone, substantially without losing its stratified character. Here, the central current is much stronger and erodes the top of the bed, where the middlings are now exposed. The high middlings are swept up and discharged through the vortex finder.

The heavy middlings that spiral upward in the central current may bypass the orifice of the lower vortex finder owing to their higher specific gravity. Consequently, the coarse heavy middlings fraction tends to recirculate to the stratified bed and finally enters the third conical section. In this last section (III), the bed is finally destroyed as coarse particles fan out along the cyclone wall in a single layer, exposing the small particles that so far have been protected from being washed out. The central current in Section III is relatively weak as it has nearly spent itself in the previous sections. The upward current that remains separates the small particles from the remainder of the material, with preference for those of low specific gravity. Thus the fine, light particles are finally discharged through the vortex finder by a process of elutriation. The heavy particles, fine as well as coarse, are discharged through the apex. The separation thus takes place in three steps, (Figure 2).



COMPOUND WATER CYCLONE

(Cyclone Engineering)

CLASSIFYING CYCLONE

(McNally Pittsburg)

FIGURE 1: Comparison of Design Features of a Compound Water Cyclone and a Classifying Cyclone.

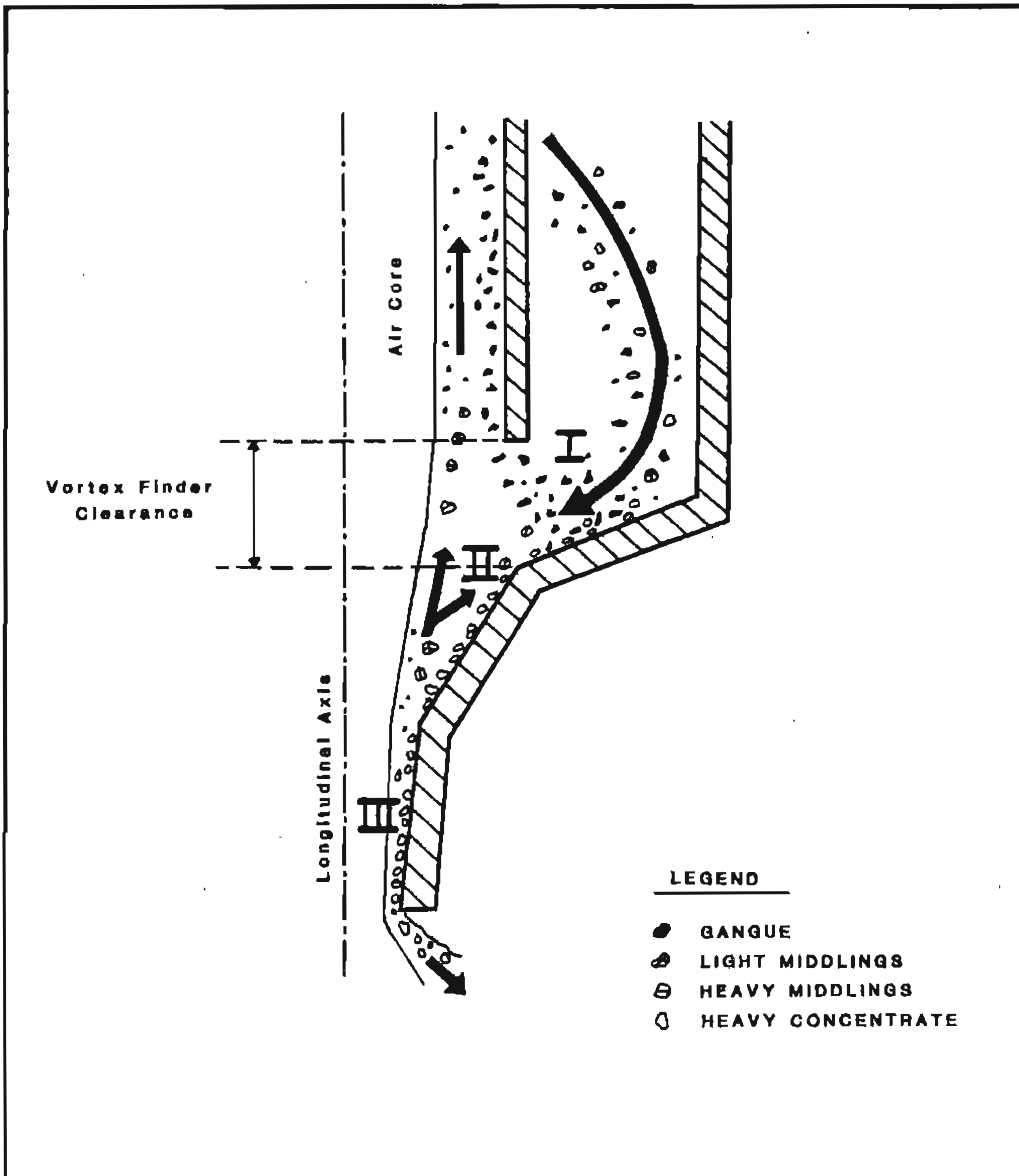


FIGURE 2: Separating process in a Compound Water Cyclone (15)

Experimental Procedure

A review of the literature as cited above indicated to the authors that for short duration bench scale testing, a CW cyclone of pyrex glass could be used. Figure 3 is a diagram of the CW cyclone, which was fabricated from pyrex glass. The vortex finder can be moved to adjust its position. The apex is varied by fitting tygon tubing inserts in the orifice. Figure 4 is a closeup photograph of the CW cyclone. Figure 5 shows the experimental setup with a constant head tank arranged for accurately adjusting the head for the CW cyclone.

Several tests were conducted to determine the optimum water head for the feed tank and the optimum diameter of the apex orifice. The vortex finder diameter was kept constant. The apex orifice diameter of 1/4" was chosen to allow most of the inlet feed to overflow, with a minimum reporting out the apex spigot as underflow. The water (feed) head was set at 55 inches, again to obtain maximum overflow. The test conditions used were as follows:

cyclone head	55 in. (139.7 cm.)
apex orifice	1/4 in. (0.635 cm.)
vortex finder diameter	1 in. (2.540 cm.)
flow rate:	overflow = 8.24 gal./min. (31. liters/min.)
	underflow = 0.15 gal./min. (.58 liters/min.)

Figure 6 shows the general flow sheet followed in this project. For two of the samples tested, the feed material was screened at 65 mesh. For one sample, the feed was screened at 48 mesh. All oversize material was rejected. The wet screened feed was slurried and fed manually from the head tank to the primary CW cyclone at a constant rate and the products were collected. The CW cyclone underflow for Lillian Creek sample was deslimed (wet screened) over 400 mesh and the +400 material was passed through the secondary CW cyclone. Both the overflow and underflow secondary CW cyclone products were sink-floated at 2.85 and 3.33 specific gravities. Gold particles from the 3.33 sink fractions of both underflow and overflow products were hand picked under the microscope and/or analyzed chemically. All of the float-sink products (2.85 float, 2.85-3.33, and 3.33 sink) were screened for size analysis. The 3.33 specific gravity sinks form only a small percentage of the whole, and in order to preserve accuracy, all data were calculated to 4 decimals.

Sources of Samples

Three placer mine samples were tested in this project. All three were geologically similar; i.e. stream alluvium. The samples and sources were as follows:

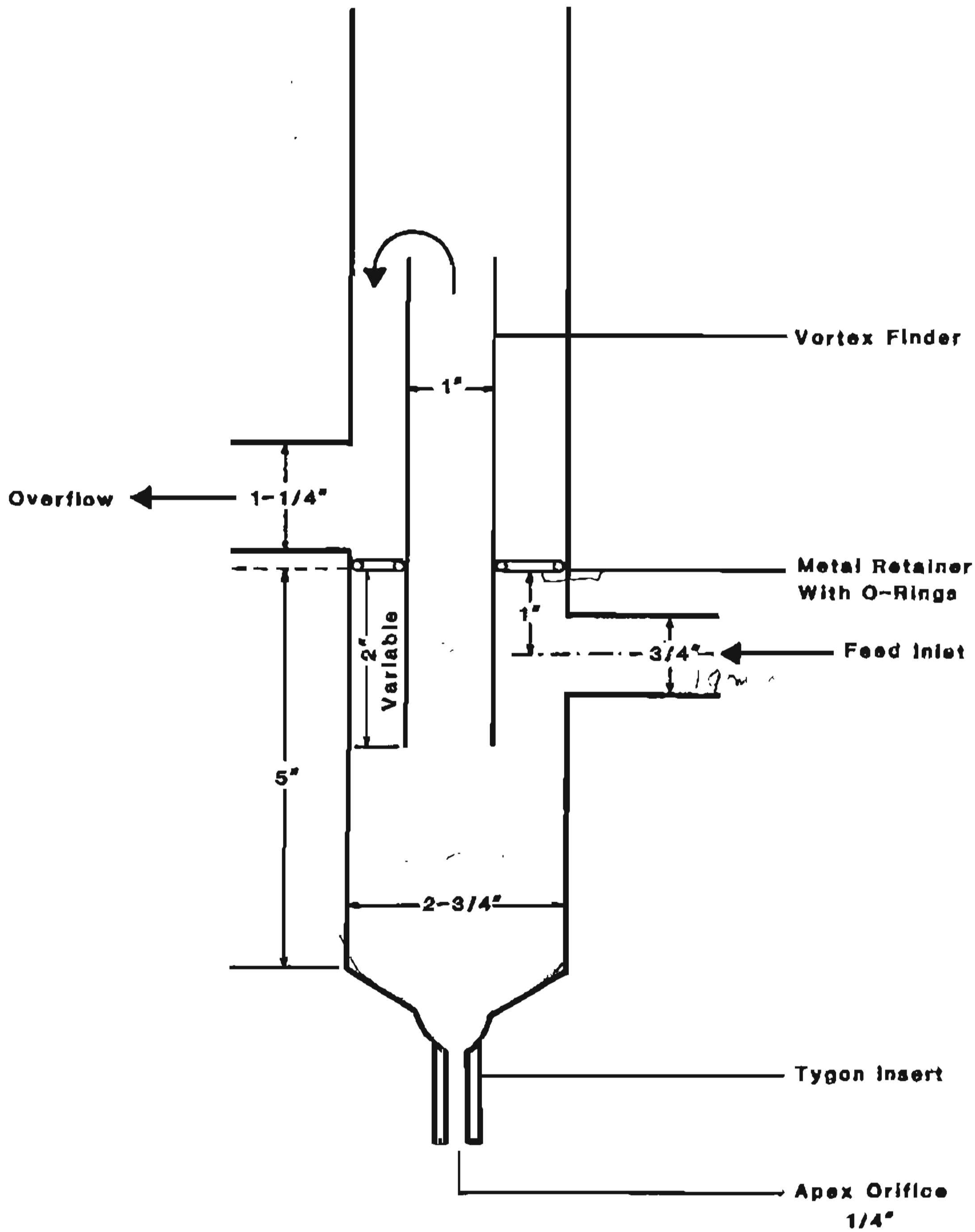


FIGURE 3: Design of Pyrex Compound Water Cyclone Used for Laboratory Investigations

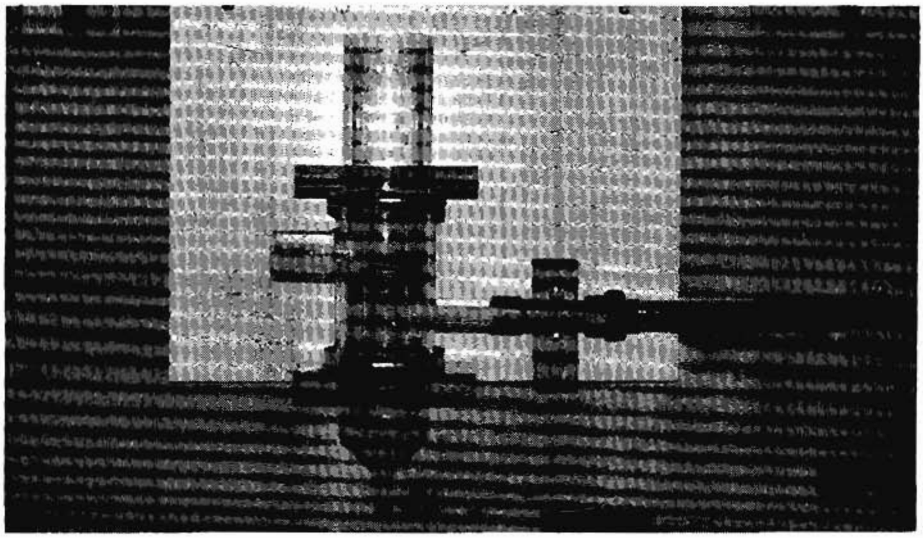


Figure 4: A closeup photograph of the compound water cyclone

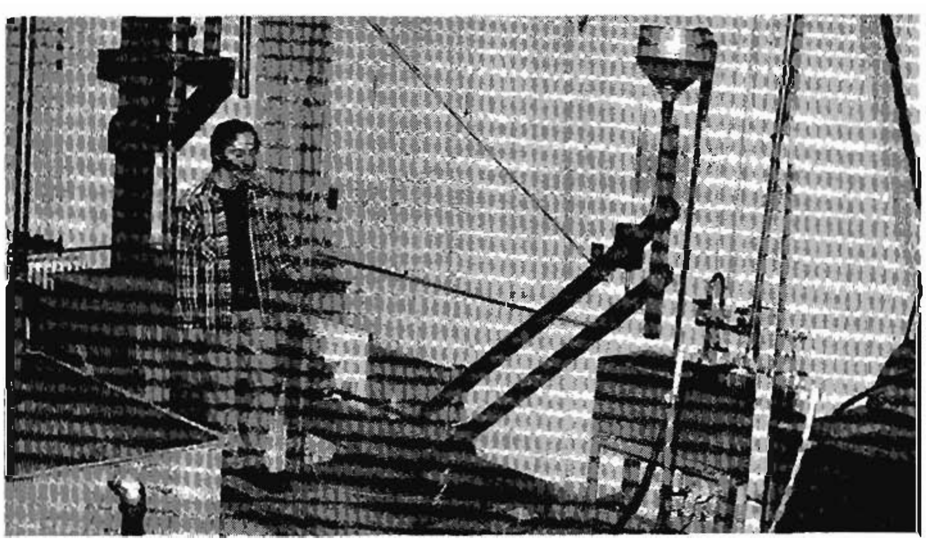


Figure 5: Experimental setup with a constant head tank

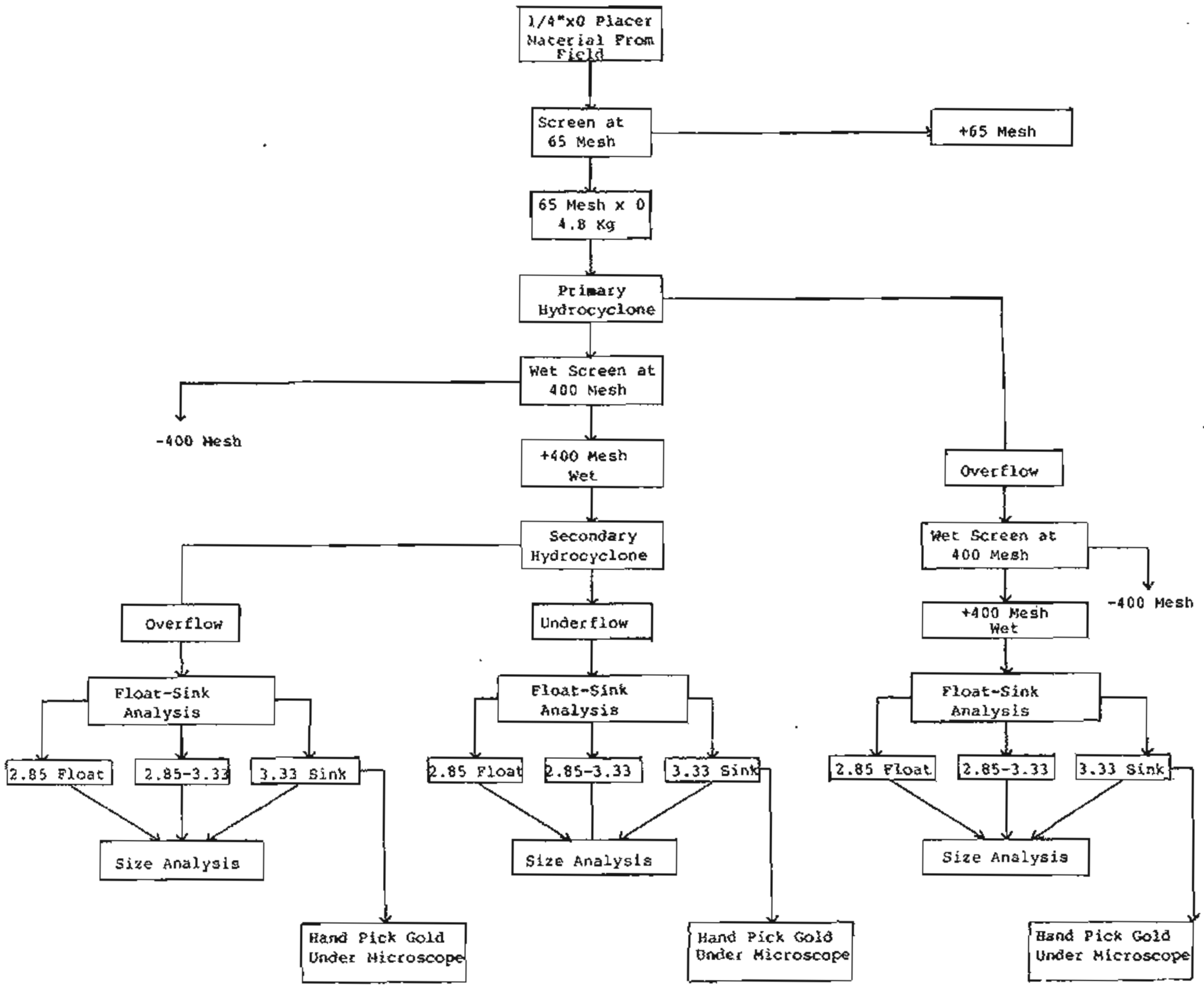


Figure 6: Block diagram showing testing procedure followed

Creek Name	Mining District	Presumed Lode Source	Mine Owner
Lillian Creek	Livengood	Money Knob	Carl Parker (deceased)
Ready Bullion Creek	Fairbanks	Ester Dome	Jerry Hassel
Cleary Creek	Fairbanks	Pedro Dome	Oscar Tweiten

In placer mining, typically, overburden or muck has been removed to expose the gold bearing gravels. Sometimes the upper, barren gravels are also removed. The run of mine material is then processed in a sluice box, trommel or similar device to remove gravel and light coarse sands. The bucket samples which were used in this project were taken from this "scalped" material. Further description of sample preparation will be found later in this report. All three mines were located on creeks about one half mile downstream from the nearest known lode deposit.

Experimental Results

Lillian Creek, (Livengood) Sample

Table 1 gives the distribution of various size and specific gravity fractions as a weight percent of feed to the primary CW cyclone. The primary CW cyclone rejected 76% of the feed with very little loss of 3.33 sinks. The feed to the primary CW cyclone had 37.8% -400 mesh material; only 3.1% of the feed in this size range reported to the underflow. Note that the -400 mesh fraction appears twice, once as wet and once as dry. The initial wet screening removed most of the -400 mesh material (Figure 6). The -400 mesh dry material appeared in the size analyses of float-sink products.

The gold recovered was as follows:

	No. of Gold Particles	Gold Weight, Milligrams	Gold Recovered, Percent
Primary CW cyclone overflow	1	0.1	.2
Secondary CW cyclone overflow	3	0.1	.2
Secondary CW cyclone underflow	1130	51.2	99.6

Thus a recovery of more than 99.5% of the gold has been achieved in the two passes through the CW cyclones. The amount of gold in the -400 mesh fraction is negligible, in fact, very little if any gold was found that was finer than 200 mesh.

Table 2 shows the distribution of various size fractions as a percentage of each of the three specific gravity fractions, 2.85 floats, 2.85 to 3.33, and 3.33 sinks. In the primary CW cyclone, for 2.85 floats, the 65x100 mesh reported more in underflow than overflow; the 100x150 mesh underflow and overflow reported about equally, whereas for sizes smaller than 150 mesh, rejection of material to overflow was more efficient.

Primary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	11.6973	.4760	.0392	12.2125
100x150	14.4670	.4094	.0352	14.9116
150x200	13.6392	.1439	.0403	13.8234
200x270	9.6132	.0295	.0067	9.6494
270x400	11.5891	.0160	.0024	11.6075
-400 Dry	9.5756	.0051	.0003	9.5810
-400 Wet	—	—	—	28.2146
TOTAL	70.5814	1.0799	.1241	100.0000

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	3.4815	.0031	.0002	3.4848
100x150	7.7378	.0052	.0003	7.7433
150x200	10.7248	.0028	.0001	10.7277
200x270	8.7369	.0011	.0000	8.7380
270x400	10.9338	.0007	.0000	10.9345
-400 Dry	9.3588	.0013	.0000	9.3601
-400 Wet	—	—	—	25.2787
TOTAL	50.9736	.0142	.0006	76.2671

Underflow

Secondary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	8.2158	.4729	.0390	8.7277
100x150	6.7292	.4042	.0349	7.1683
150x200	2.9144	.1411	.0402	3.0957
200x270	.8763	.0284	.0067	.9114
270x400	.6553	.0153	.0024	.6730
-400 Dry	.2168	.0038	.0003	.2209
-400 Wet	—	—	—	2.9359
TOTAL	19.6078	1.0657	.1235	23.7329

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	.3862	.0170	.0011	.4043
100x150	.8940	.0321	.0018	.9279
150x200	1.1541	.0296	.0014	1.1851
200x270	.5800	.0119	.0004	.5923
270x400	.5406	.0094	.0006	.5506
-400 Dry	.1228	.0016	.0001	.1245
TOTAL	3.6777	.1016	.0054	3.7847

Underflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	7.8296	.4559	.0379	8.3234
100x150	5.8352	.3721	.0331	6.2404
150x200	1.7603	.1115	.0388	1.9106
200x270	.2963	.0165	.0063	.3191
270x400	.1147	.0059	.0018	.1224
-400 Dry	.0940	.0022	.0002	.0964
TOTAL	15.9301	.9641	.1182	17.0123

TABLE 1

Size - specific gravity distribution of products of two stage CW cyclone concentration of -65 mesh gold placer material, Lillian Creek, (Livengood) Figures in weight percent of total feed.

Primary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	16.57	44.08	31.59
100x150	20.50	37.91	28.37
150x200	19.32	13.33	32.47
200x270	13.62	2.73	5.40
270x400	16.42	1.48	1.93
-400 Dry	13.57	.47	.24
TOTAL	100.00	100.00	100.00

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	4.93	.29	.16
100x150	10.96	.48	.24
150x200	15.19	.26	.08
200x270	12.38	.10	.00
270x400	15.49	.06	.00
-400 Dry	13.26	.12	.00
TOTAL	72.21	1.31	.48

Underflow

Secondary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	11.64	43.79	31.43
100x150	9.54	37.43	28.13
150x200	4.13	13.07	32.39
200x270	1.24	2.63	5.40
270x400	.93	1.42	1.93
-400 Dry	.31	.35	.24
TOTAL	27.79	98.69	99.52

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	.55	1.57	.89
100x150	1.27	2.97	1.45
150x200	1.64	2.74	1.13
200x270	.82	1.10	.32
270x400	.77	.87	.48
-400 Dry	.17	.15	.08
TOTAL	5.22	9.40	4.35

Underflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	11.09	42.22	30.54
100x150	8.27	34.46	26.68
150x200	2.49	10.33	31.26
200x270	.42	1.53	5.08
270x400	.16	.55	1.45
-400 Dry	.14	.20	.16
TOTAL	22.57	89.29	95.17

TABLE 2

Distribution of density fractions as a percent of each size fraction in a two stage CW cyclone concentration of -65 mesh gold placer material, Lillian Creek, (Livengood).

The primary CW cyclone underflow recovered 99.52% of the 3.3 sinks and 98.69% of the 2.85 to 3.33 specific gravity fractions.

Table 3 shows distribution of each size and specific gravity fraction. The secondary CW cyclone underflow shows that for 3.33 sinks, recovery is quite good down to 270 mesh and falls off rapidly below that. It is to be expected that gold recovery will continue to be good for sizes down to 400 mesh and smaller, since gold is so much denser than the average 3.33 sinks.

Ready Bullion Creek (Ester Dome) Sample

Table 4 gives the distribution of various size and specific gravity fractions as a weight percent of feed to the primary CW cyclone. The primary CW cyclone rejected 40% of the feed with very little loss of 3.33 sinks. The feed to the primary CW cyclone had 18% minus 400 mesh material; only 1.7% of the feed in this size range reported to the underflow. The gold recovered was as follows:

	Gold Recovered, Percent
Primary CW cyclone overflow	.1
Secondary CW cyclone overflow	3.9
Secondary CW cyclone underflow	96.0

Thus a recovery of 96% of the gold has been achieved in the two passes through the CW cyclones.

Table 5 shows the distribution of various size fractions as a percentage of each of the three specific gravity fractions, 2.85 floats, 2.85 to 3.33, and 3.33 sinks. In the primary CW hydrocyclone, for 2.85 floats, the 65x100 mesh reported sixteen times more in underflow than overflow; the 100x150 mesh underflow was three times the overflow, whereas for sizes smaller than 150 mesh, rejection of material to overflow was more efficient.

The primary CW cyclone underflow recovered 96.91% of the 3.3 sinks and 99.63% of the 2.85 to 3.33 specific gravity fractions.

Table 6 shows distribution of each size and specific gravity fraction. The secondary CW cyclone underflow shows that for 3.33 sinks recovery is quite good down to -400 mesh. It was expected that gold recovery would continue to be good for sizes down to 400 mesh and smaller, since gold is so much denser than the average 3.33 sinks.

Cleary Creek (Pedro Dome) Sample

Table 7 gives the distribution of various size and specific gravity fractions as a weight percent of feed to the primary CW cyclone. The primary CW cyclone rejected 82% of the feed with very little loss of 3.33 sinks. The

Primary C.W. Cyclone Feed

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	100	100	100
100x150	100	100	100
150x200	100	100	100
200x270	100	100	100
270x400	100	100	100
-400 Dry	100	100	100

Overflow

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	29.75	.65	0.51
100x150	53.46	1.27	0.85
150x200	78.62	1.95	0.25
200x270	90.89	3.66	0.00
270x400	94.34	4.05	0.00
-400 Dry	97.72	25.53	0.00

Underflow

Secondary C.W. Cyclone Feed

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	70.25	99.35	99.49
100x150	46.53	98.73	99.15
150x200	21.38	98.05	99.75
200x270	9.11	96.34	100.00
270x400	5.66	95.95	100.00
-400 Dry	2.28	74.47	100.00

Overflow

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	3.33	3.57	2.82
100x150	6.19	7.83	5.11
150x200	8.49	20.55	3.48
200x270	6.03	40.29	5.92
270x400	4.69	58.79	24.87
-400 Dry	1.25	31.91	33.33

Underflow

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	66.92	95.78	96.67
100x150	40.34	90.90	94.04
150x200	12.89	77.50	96.27
200x270	3.08	56.05	94.08
270x400	0.97	37.16	75.13
-400 Dry	1.03	42.56	66.67

TABLE 3

Distribution of density fractions in weight percent for each size in a two stage CW cyclone concentration of -65 gold placer material, Lillian Creek, (Livengood).

Primary C.W. Cyclone Feed

Size Mesh	2.85F	2.85S 3.33F	1.11S	Total
65x100	40.1385	3.4078	.8588	44.4051
100x150	10.2623	1.3418	.3113	11.9154
150x200	6.9688	.7836	.1763	7.9287
200x270	5.2690	.3936	.0558	5.7184
270x400	11.1666	.3613	.0349	11.5628
-400	18.0625	.3776	.0295	18.4696
TOTAL	91.8677	6.6657	1.4666	100.0000

Specific Gravity

Overflow

Size Mesh	2.85F	2.85S 3.33F	3.33S	Total
65x100	2.3657	.0024	.0446	2.4127
100x150	2.6856	.0022	.0002	2.6880
150x200	4.1765	.0044	.0001	4.1810
200x270	4.2978	.0025	.0001	4.3004
270x400	10.2037	.0096	.0001	10.2134
-400	16.7323	.0041	.0001	16.7365
TOTAL	40.4616	.0252	.0452	40.5320

Specific Gravity

Underflow

Secondary C.W. Cyclone Feed

Size Mesh	2.85F	2.85S 3.33F	3.33S	Total
65x100	37.7728	3.4054	.8142	41.9924
100x150	7.5767	1.3396	.3111	9.2274
150x200	2.7923	.7792	.1762	3.7477
200x270	.9712	.3911	.0557	1.4180
270x400	.9629	.3517	.0348	1.3494
-400	1.3302	.3735	.0294	1.7331
TOTAL	51.4061	6.6405	1.4214	59.4680

Specific Gravity

Overflow

Size Mesh	2.85F	2.85S 3.33F	3.33S	Total
65x100	13.8020	1.9209	.1574	15.8803
100x150	3.9795	.8191	.0580	4.8566
150x200	1.7813	.4725	.0263	2.2801
200x270	.7321	.2060	.0067	.9448
270x400	.7742	.2303	.0047	1.0092
-400	1.1140	.2683	.0062	1.3885
TOTAL	22.1831	3.9171	.2593	26.3595

Specific Gravity

Underflow

Size Mesh	2.85F	2.85S 3.33F	3.33S	Total
65x100	23.9708	1.4845	.6568	26.1121
100x150	3.5972	.5205	.2531	4.3708
150x200	1.0111	.3068	.1499	1.4678
200x270	.2391	.1851	.0490	.4732
270x400	.1887	.1215	.0301	.3403
-400	.2167	.1052	.0232	.3451
TOTAL	29.2236	2.7236	1.1621	33.1093

Specific Gravity

TABLE 4

Size - specific gravity distribution of products of two stage CW cyclone concentration of -65 mesh gold placer, Ready Bullion Creek (Ester). Figure in weight percent of total feed.

Primary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	43.67	51.13	58.57
100x150	11.17	20.13	21.24
150x200	7.58	11.76	12.03
200x270	5.73	5.90	3.81
270x400	12.15	5.42	2.34
-400	19.70	5.66	2.01
TOTAL	100.00	100.00	100.00

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	2.57	.04	3.04
100x150	2.92	.03	.01
150x200	4.54	.07	.01
200x270	4.68	.04	.01
270x400	11.10	.13	.01
-400	18.25	.06	.01
TOTAL	44.06	.37	3.09

Underflow

Secondary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	41.11	51.09	55.52
100x150	8.24	20.10	21.21
150x200	3.04	11.69	12.01
200x270	1.06	5.87	3.80
270x400	1.04	5.28	2.37
-400	1.45	5.60	2.00
TOTAL	55.94	99.63	96.91

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	15.04	28.82	10.73
100x150	4.33	12.29	3.95
150x200	1.94	7.09	1.79
200x270	.80	3.09	.46
270x400	.84	3.45	.32
-400	1.21	4.03	.42
TOTAL	24.16	58.77	17.67

Underflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	26.07	22.27	44.79
100x150	3.91	7.81	17.26
150x200	1.10	4.60	10.22
200x270	.26	2.78	3.34
270x400	.20	1.82	2.05
-400	.24	1.58	1.58
TOTAL	31.78	40.86	79.24

TABLE 5

Distribution of density fractions as a percent of each size fraction in a two stage CW cyclone concentration of -65 mesh gold placer material, Ready Bullion Creek (Ester).

Primary C.W. Cyclone Feed

Size Mesh	2.85F	2.85 -3.33	3.33S
	Specific Gravity		
65x100	100	100	100
100x150	100	100	100
150x200	100	100	100
200x270	100	100	100
270x400	100	100	100
-400	100	100	100

Overflow

Size Mesh	2.85F	2.85 -3.33	3.33S
	Specific Gravity		
65x100	5.88	.08	5.19
100x150	26.16	.15	.05
150x200	59.89	.60	.08
200x270	81.53	.67	.26
270x400	91.43	2.40	.42
-400	92.64	1.06	.50

Underflow

Secondary C.W. Cyclone Feed

Size Mesh	2.85F	2.85 -3.33	3.33S
	Specific Gravity		
65x100	94.12	99.92	94.81
100x150	73.84	99.85	99.95
150x200	40.11	99.40	99.92
200x270	18.47	99.33	99.74
270x400	8.57	97.60	99.58
-400	7.36	98.94	99.50

Overflow

Size Mesh	2.85F	2.85 -3.33	3.33S
	Specific Gravity		
65x100	34.43	56.37	18.32
100x150	38.80	61.05	18.61
150x200	25.60	60.29	14.89
200x270	13.93	52.29	12.08
270x400	6.92	63.89	13.45
-400	6.14	71.07	20.90

Underflow

Size Mesh	2.85F	2.85 -3.33	3.33S
	Specific Gravity		
65x100	59.69	43.55	76.49
100x150	35.04	38.80	81.34
150x200	14.51	39.11	85.03
200x270	4.54	47.04	88.66
270x400	1.65	33.71	86.13
-400	1.22	27.87	78.60

TABLE 6

Distribution of density fractions in weight percent for each size in two stage CW cyclone concentration of -65 gold placer material, Ready Bullion Creek (Ester).

Primary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	26.2005	1.0606	.8655	28.1266
100x150	12.7465	.4424	.3543	13.5432
150x200	11.7992	.1803	.2019	12.1814
200x270	7.7339	.0394	.0494	7.8227
270x400	9.8286	.0347	.0155	9.8788
-400 Dry	6.3557	.0222	.0055	6.3834
-400 Wet	—	—	—	22.0639
TOTAL	74.6644	1.7796	1.4921	100.0000

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	15.9568	.6238	.2638	16.8444
100x150	10.0335	.3392	.1984	10.5711
150x200	10.0797	.1359	.1334	10.3490
200x270	7.0017	.0240	.0340	7.0597
270x400	9.1847	.0221	.0099	9.2167
-400 Dry	5.4604	.0087	.0006	5.4697
-400 Wet	—	—	—	22.0639
TOTAL	57.7204	1.1537	.6401	81.5745

Underflow

Secondary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	10.2437	.4368	.6017	11.2822
100x150	2.7130	.1032	.1559	2.9721
150x200	1.7195	.0444	.0685	1.8324
200x270	.7322	.0154	.0154	.7630
270x400	.6439	.0126	.0056	.6621
-400	.8953	.0135	.0049	.9137
TOTAL	16.9476	.6259	.8520	18.4255

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	8.8181	.2866	.4548	9.5594
100x150	2.3378	.0651	.1323	2.5350
150x200	1.5283	.0254	.0581	1.6118
200x270	.6787	.0102	.0130	.7019
270x400	.6148	.0093	.0048	.6289
-400	.8748	.0117	.0048	.8913
TOTAL	14.8525	.4083	.6676	15.9283

Underflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S	Total
65x100	1.4257	.1485	.1469	1.7211
100x150	.3752	.0382	.0238	.4372
150x200	.1912	.0189	.0104	.2205
200x270	.0534	.0052	.0024	.0610
270x400	.0291	.0032	.0008	.0331
-400	.0205	.0018	.0001	.0224
TOTAL	2.0951	.2158	.1844	2.4953

TABLE 7

Size - specific gravity distribution of products of two stage CW cyclone concentration of -48 mesh gold placer, Cleary Creek (Pedro). Figures in weight percent of total feed.

feed to the primary CW cyclone had 28.4% -400 mesh material; only 0.9% of the feed in this size range reported to the underflow. The gold recovered was as follows:

	Gold Recovered, Percent	Conc. Ratio
primary o'flow	4.4	5.4
Sec. ~~Primary~~ CW cyclone overflow	9.7	7.4
Test. ~~Secondary~~ CW cyclone overflow	1.9	5.7
Secondary CW cyclone underflow	84.0	

Thus a recovery of 84% of the gold has been achieved in the two passes through the CW cyclones. Higher loss of gold is attributable to the high ratio of concentration i.e., 5.4 for the primary and 7.4 in the secondary stage. It is expected that lower ratios of concentration will improve recovery.

Table 8 shows the distribution of various size fractions as a percentage of each of the three specific gravity fractions, 2.85 floats, 2.85 to 3.33, and 3.33 sinks. In the primary CW hydrocyclone, for 2.85 floats, all size fractions reported more into overflow than underflow. Rejection of material to overflow was efficient for all sizes.

The primary CW cyclone underflow recovered a little over half (57.1%) of the 3.3 sinks and only 35.2% of the 2.85 to 3.33 specific gravity fractions.

Table 9 shows distribution of each size and specific gravity fraction. The secondary CW cyclone underflow shows that 3.33 sinks are rejected in overflow even at 65x100 mesh. This is attributable to high ratio of concentration achieved for the two stage operation.

Discussion

The tests show that the CW cyclone can recover gold efficiently from -65 mesh placer material. Sink-float tests show that the CW cyclone performed exceedingly well for concentration of heavy minerals of density greater than 3.33 and coarser than 270 mesh.

The effectiveness of separation in the second CW cyclone is shown on Tables 3, 6 and 9. In the primary CW cyclone, at low ratio of concentration more than 99% of the 3.33 sinks reported in all size ranges (Tables 3 and 6). At high ratio of concentration much of the 3.3 sinks were rejected in the overflow (Table 9). In the secondary CW cyclone these percentages drop to about 66% for the smaller sizes (-400 mesh dry). This may be attributed to the fact that smaller sizes are separated at a higher pulp density, moreover the secondary cyclone separates at a higher pulp density than the primary cyclone. The small amount of material available for feed for the CW cyclone was insufficient to build up the pulp density.

Primary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	35.10	59.60	58.00
100x150	17.07	24.86	23.75
150x200	15.80	10.13	13.53
200x270	10.36	2.21	3.31
270x400	13.16	1.95	1.04
-400	8.51	1.25	.37
TOTAL	100.00	100.00	100.00

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	21.37	35.05	17.68
100x150	13.44	19.06	13.30
150x200	13.50	7.64	8.94
200x270	9.38	1.35	2.28
270x400	12.30	1.24	.66
-400	7.31	.49	.04
TOTAL	77.30	64.83	42.90

Underflow

Secondary C.W. Cyclone Feed

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	13.73	24.54	40.32
100x150	3.63	5.80	10.45
150x200	2.30	2.49	4.59
200x270	.98	.87	1.03
270x400	.86	.71	.38
-400	1.20	.76	.33
TOTAL	22.70	35.17	57.10

Overflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	11.81	16.10	30.48
100x150	3.13	3.66	8.85
150x200	2.05	1.43	3.89
200x270	.91	.53	.87
270x400	.82	.52	.32
-400	1.17	.66	.32
TOTAL	19.89	22.94	44.74

Underflow

Size Mesh	Specific Gravity 2.85F	2.85 -3.33	3.33S
65x100	1.91	8.34	9.85
100x150	.50	2.15	1.60
150x200	.26	1.06	.70
200x270	.07	.29	.16
270x400	.04	.18	.05
-400	.03	.10	.01
TOTAL	2.81	12.13	12.36

TABLE 8

Distribution of density fractions as a percent of each size fraction in a two stage CW cyclone concentration of -65 mesh gold placer material, Cleary Creek (Pedro).

Primary C.W. Cyclone Feed

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	100	100	100
100x150	100	100	100
150x200	100	100	100
200x270	100	100	100
270x400	100	100	100
-400	100	100	100

Overflow

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	60.90	58.82	30.48
100x150	78.72	76.67	56.00
150x200	85.43	75.37	66.07
200x270	90.53	60.91	68.83
270x400	93.45	63.69	63.87
-400	85.91	39.19	10.91

Underflow

Secondary C.W. Cyclone Feed

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	39.10	41.18	69.52
100x150	21.28	23.33	44.00
150x200	14.57	24.63	33.93
200x270	9.47	39.09	31.17
270x400	6.55	36.31	36.13
-400	14.09	60.81	89.09

Overflow

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	33.66	27.02	52.55
100x150	18.34	14.72	37.28
150x200	12.95	14.09	28.78
200x270	8.79	25.89	26.31
270x400	6.25	26.80	30.97
-400	13.76	52.70	87.27

Underflow

Specific Gravity

Size Mesh	2.85F	2.85 -3.33	3.33S
65x100	5.44	14.16	16.97
100x150	2.94	8.61	6.72
150x200	1.62	10.54	5.15
200x270	.68	13.20	4.86
270x400	.30	9.51	5.16
-400	.33	8.11	1.82

TABLE 9

Distribution of density fractions in weight percent for each size in two stage CW cyclone concentration of -65 gold placer material, Cleary Creek (Pedro).

Summary and Conclusions

Summary

One of the best prospects for improving recovery of gold and other heavy minerals contained in Alaskan placer deposits is the concentrating water cyclone. This device has been widely used in other mining regions to beneficiate incoherent ores.

A custom made compound water hydrocyclone (CW cyclone) was used for conducting research studies on the applicability of such devices to Alaskan mineral preparation problems. The mining industry is looking for more sophisticated techniques in order to win good recoveries of fine gold from placers.

Three placer gold samples were tested and the CW cyclone was shown to be a practical device for recovering gold and other heavy minerals. It is expected that the mining industry will consider the installation and use of this equipment. Reserves of strategically important metals are known to exist in Alaska. Concentrating water cyclones could play an important role in the recovery of these metals. Immediate applications, however, could be for the recovery of gold finer than 65 mesh from gold placers.

Conclusions

The objective of the project was to test the efficiency of concentration of gold placer material with the CW cyclone, and to produce concentrates. The results of the tests indicate that the CW cyclone can concentrate placer material efficiently, and indicate further field testing in a circuit using larger CW cyclones.

In light of the encouraging results obtained in this study and reported herein, a pilot scale test system is now being assembled. As a practical matter, small mine operations will need to see "first hand" the application of the CW cyclone before seriously considering its purchase and utilization. The equipment and test procedure proposed for a follow up study is described below.

A representative sample of each potential feed will be tested for its amenability to CW cyclones for mineral beneficiation. The field sample will be screened at 10 mesh.

The minus 10 mesh sample will then be tested to determine separation potential using CW cyclone techniques. Tests would be carried out using two 4" CW cyclones. The cyclone could accept feed with a top size of 3/16" (5 mm). The test cyclone would be fed from a centrifugal pump, and the overflow and underflow could be returned direct to the pump feed tank. Sampling could be carried out by cutting both product streams simultaneously, generally for a period of 5 seconds.

The operating conditions include, for example, variations in feed pulp density, feed pressure, cone type and vortex finder clearance. The planned test setup is shown in Figure 7.

The two-stage separator process has been selected in order to improve the overall result of the separation by producing a clean overflow product in the primary CW cyclone and a clean underflow product in the secondary CW cyclone, and by recirculating a middlings product to the feed. It has been recognized that the CW cyclone, having a wide application, requires great flexibility and control. Solids and water are fed into a mixing tank at a constant rate to produce a slurry having a solids content of 8-15 percent, by weight. This pulp is fed into the primary CW cyclone by a slurry pump. The overflow product of primary CW cyclone is fed directly into a conventional 4" dewatering cyclone from which dewatered waste is obtained. The overflow of the latter cyclone may be reused to supply water for dilution of the primary CW Cyclone feed. The overflow product of CW Cyclone II is returned to the mixing tank as middlings, and the underflow, which is partially dewatered, is the concentrate. Water for diluting the feed for CW Cyclone II back to the original solids concentration is provided, at the required pressure, by the pulp divider.

The primary 4" CW cyclone will be operated under an inlet pressure that is sufficient to effect separation in the two following cyclones as well. For example, the inlet pressure of CW Cyclone I may be 15 psi, the inlet pressure of CW Cyclone II will be 7 psi and the inlet pressure of the dewatering or classifier cyclone will also be 8 psi. This leaves an 8 psi pressure drop for the primary CW Cyclone I. For sands, these pressures should be somewhat higher in view of the higher average specific gravity of the material. Inlet pressures of 20 psi per stage are required when using 8" CW cyclones. The pressures required for small cyclones are lower than those for large cyclones. They are in the order of 5 to 10 psi per stage, depending on whether coal, sand or ore is being processed (9).

As results of the tests above are analyzed, those techniques which are most promising will be pursued, viz modify CW cyclone feed size, feed rate, wash water rates, recycle advantages etc.

Based on an analysis of the best results produced from the process above, preliminary flow sheets can be developed. These would indicate estimated yields of products and grades. Plant design for appropriate flow sheets can then be developed and costed out.

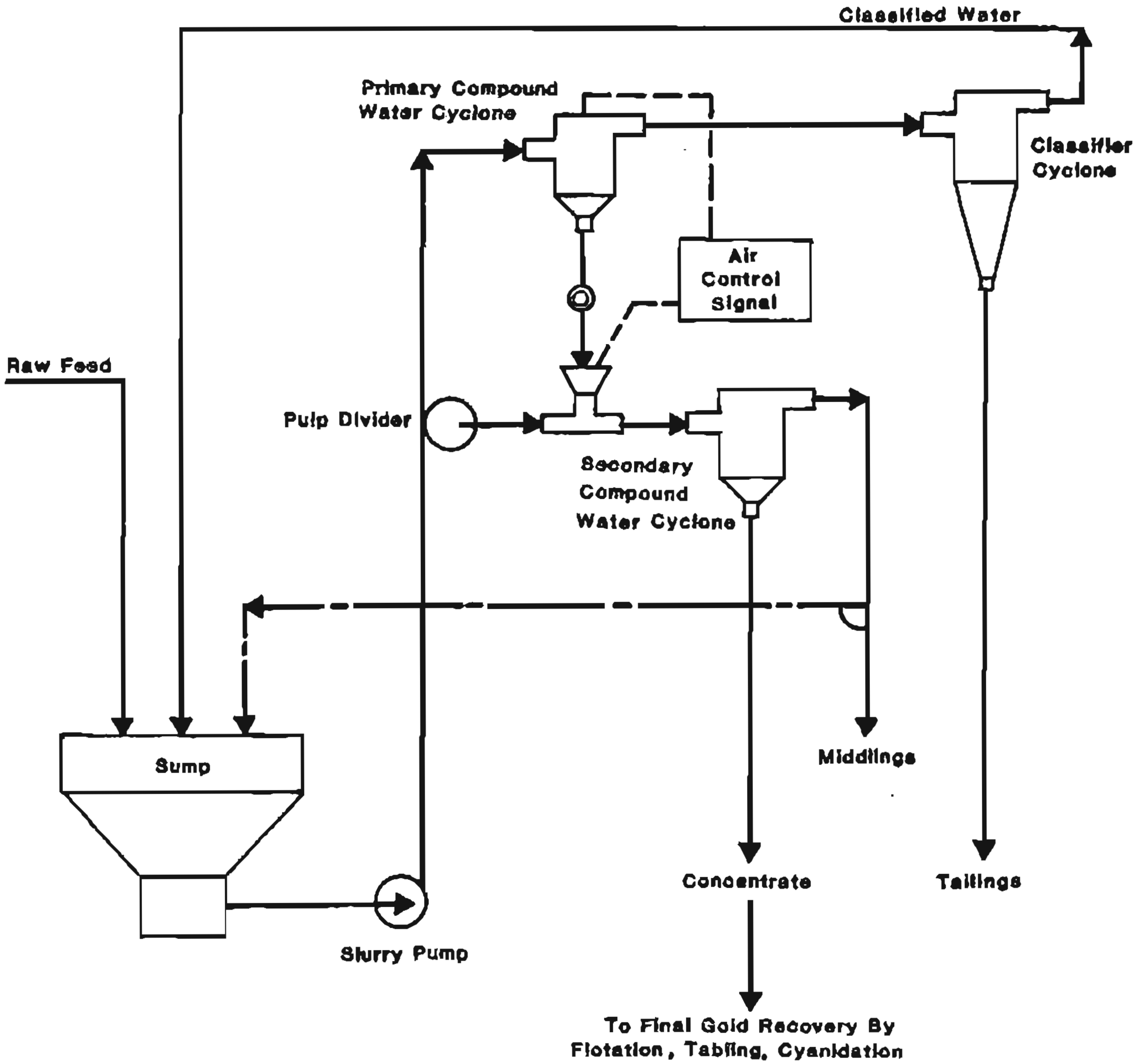


FIGURE 7: Two-Stage Compound Water Cyclone Concentration With Automatic Control (Cyclone Engineering Sales Ltd., Canada)

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